

# GRB051210: *Swift* detection of a short gamma ray burst

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Received xxxx, 2006/ accepted xxxx, 2006

## ABSTRACT

**Context.** The short/hard GRB051210 was detected and located by the *Swift*-BAT instrument and rapidly pointed towards by the narrow field instruments. The XRT was able to observe a bright X-ray afterglow, one of the few ever observed for this class of bursts.

**Aims.** We present the analysis of the prompt and afterglow emission of this event

**Methods.** The BAT spectrum is a power-law with photon index  $1.0 \pm 0.3$ . The X-ray light curve decays with slope  $-2.58 \pm 0.11$  and shows a small flare in the early phases. The spectrum can be described with a power law with photon index  $1.54 \pm 0.16$  and absorption  $(7.5^{+4.3}_{-3.2}) \times 10^{20} \text{ cm}^{-2}$

**Results.** We find that the X-ray emission is consistent with the hypothesis that we are observing the curvature effect of a GRB occurred in a low density medium, with no detectable afterglow. We estimate the density of the circumburst medium to be lower than  $4 \times 10^{-3} \text{ cm}^{-3}$ . We also discuss different hypothesis on the possible origin of the flare.

**Key words.** gamma rays: bursts, gamma-ray bursts: individual (GRB051210)

## 1. Introduction

It has long been known that the  $T_{90}$  duration and hardness ratio of the population of gamma-ray bursts (GRBs) show a bimodal distribution, where two classes can be identified: long GRBs, with duration longer than 2 seconds and short GRBs lasting less than 2 seconds and showing a harder spectrum (Mazets et al., 1981; Norris et al., 1984; Kouveliotou et al., 1981). While long GRBs have been studied in good detail and their origin is now established in the explosion of massive stars leading to very energetic core collapse supernovae (e.g. Woosley, 1993; Bloom et al., 1999; Hjorth et al., 2003), very little was known about short GRBs, mainly because of the difficulty to localize them with good accuracy. A good progenitor candidate for short GRBs has been identified in the merger of two compact objects in a tight binary (e.g. Eichler et al., 1989). Thanks to the rapid repointing capability of the *Swift* satellite (Gehrels et al., 2004), that allows for an accurate localization of the afterglow within few minutes from the burst onset, this gap is now being filled, and up to now seven short GRBs have been localized and their afterglow detected (GRB050509B: Gehrels et al., 2005; Bloom et al., 2005a; GRB050709: Villaseñor et al., 2005; Fox et al., 2006; GRB050724: Barthelmy et al., 2005b; Campana et al., 2005; GRB050813: Fox et al., 2006; GRB051210 Mangano et al.,

2005a, GRB051221A: Parsons et al., 2005; GRB060121: Arimoto et al., 2006). The association of two of these events (GRB050509B and GRB050724) with late-type galaxies and the amount of energy involved (significantly lower than for long GRBs) support the hypothesis that short/hard bursts are the product of the merger of two compact objects in a binary system. The lack of any supernova signature in the identified host galaxies confirms this idea. On the other hand, the association of GRB050709 and GRB051221A with star forming galaxies is not at variance with this hypothesis, and merely extends the range of possible lifetimes of the progenitor system, which can be located both in early-type, old population galaxies, and in star-forming galaxies.

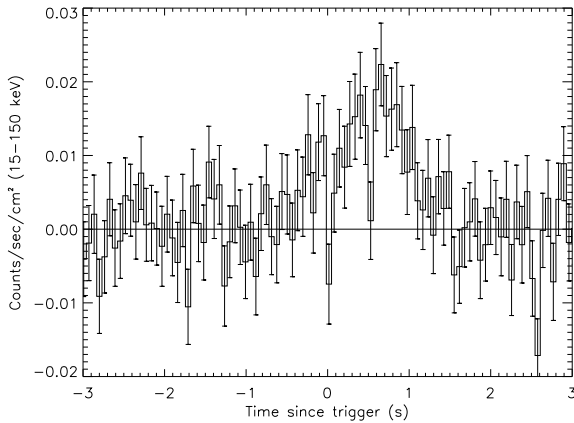
GRB051210 triggered the *Swift*-BAT instrument (Barthelmy et al., 2005a) on December 12 2005 at 05:46:21 UT (Mangano et al., 2005a). The BAT position calculated on-board was RA=22h 00m 47s, Dec=-57°38'01" (J2000), with a 90% uncertainty of 3'. The burst was classified as short after the on-ground analysis of the BAT data (Sato et al., 2005; Barthelmy et al., 2005c). Barthelmy et al. (2005c) report a spectral lag of  $-0.0010^{+0.01500}_{-0.0170 \text{ sec}}$ , typical of short GRBs (Norris & Bonnell (2006)). The spacecraft slewed immediately and the XRT (Burrows et al., 2005) and UVOT (Roming et al., 2005) began observing the field 79.2 and 70 s after the trigger, respectively. The XRT onboard centroiding procedure found a bright fading uncatalogued X-ray source. No source was

detected in any of the UVOT filters (Blustin et al., 2005). Two sources were detected within the XRT error circle by the 6.5m Clay/Magellan using the LDSS3 instrument: Bloom et al. (2005b) report a clear detection of an apparently extended (north by north-east) source  $2''.9$  from the XRT position and a second marginal detection  $1''.1$  from the XRT position.

In this paper we report on the analysis of the prompt and after-glow emission of GRB051210 as observed by the *Swift* X-ray instruments. Sections 2 and 3 describe the observations, the data reduction and the analysis of the BAT and XRT data respectively. The results are discussed in Sect. 4.

## 2. BAT observation

The BAT event data were re-analyzed using the standard BAT analysis software included in the HEASOFT distribution (v. 6.0.3), as described in the Swift BAT Ground Analysis Software Manual (Krimm et al., 2004), that incorporates post-launch updates to the BAT response and to the effective area and includes the systematic error vector to be applied to the spectrum. The light curve showed a double peak with  $T_{90}=1.27 \pm 0.05$  sec (Fig. 1). The average spectrum can be described with a power law with  $\Gamma = 1.1 \pm 0.3$ , with a total fluence of  $(8.1 \pm 1.4) \times 10^{-8}$  erg/cm<sup>2</sup> in the 15–150 keV band. A fit with a Band model is unconstrained.



**Fig. 1.** BAT light curve of the prompt emission of GRB051210. Each time bin is 64 ms long.

### 2.1. Data reduction

The XRT is designed to perform observations in different read-out modes (see Hill et al., 2004 for a detailed description of the XRT modes), switching automatically among them according to the count rate level of the source, in order to optimize the collected information and minimize the pile-up in the data. At present, the Imaging (*im*), Windowed Timing (*wt*) and Photon Counting (*pc*) modes are fully operating.

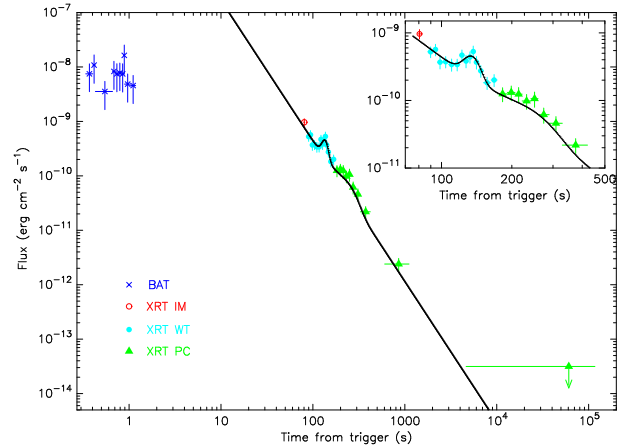
XRT began observing the field of GRB051210 in auto state and went through the correct sequence of read-out modes. The first *im* frame (lasting 2.5 sec) allowed for the on-board localization

of the burst (Mangano et al., 2005a). This was followed by 85.1 sec in *wt* mode and then by 37.0 ksec in *pc* mode.

They were calibrated, filtered and screened using the XRTDAS (v.2.3) software package to produce cleaned photon list files.

The position of the source was recalculated on ground using the task XRTCENTROID on the *pc* image and applying the boresight correction through the updated TELDEF file provided by the Swift Science Data Center (Angelini et al., 2005). The refined XRT coordinates are RA=+22h 00m 41.3s, Dec=-57°36'48''.2 (J2000), with  $4''.2$  uncertainty (Mangano et al., 2005b).

The photons for the timing and spectral analysis were extracted from a region with 20 and 30 pixels radii for *wt* and *pc* data, respectively. In order to account for the pile-up in the *pc* data, photons from a radius of 2.5 pixels around the source centroid were excluded from the analysis, and the remaining photons were then corrected by the fraction of point spread function lost. The presence of a hot column crossing the source close to the centroid was accounted for, both in the *wt* and *pc* data using a correction factor derived from the ratio of the effective areas calculated for the same region with and without the hot column. The count rate of the source during the *im* frame was obtained integrating the DN above the background in a 30 pixel radius circle and then following the procedure described in Goad et al. (2005).



**Fig. 2.** XRT light curve decay of GRB 051210. The XRT count rate (0.2–10 keV) was converted into flux units by applying a conversion factor derived from the spectral analysis. The solid line represents the best fit model to the XRT data. The BAT light curve was extrapolated into the XRT energy band by converting the BAT count rate with the factor derived from the BAT spectral parameters.

## 3. XRT observation

### 3.1. Data analysis

Figure 2 shows the BAT and XRT light curve of GRB051210. The BAT data (originally in the 15–150 keV band) were extrapolated into the XRT energy band (0.2–10 keV) and the source observed count rates converted into flux using the appropriate

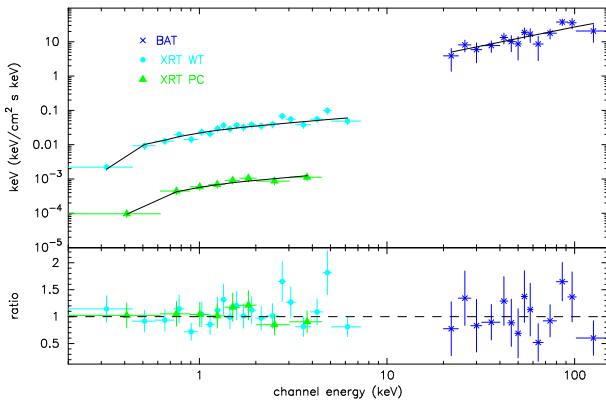
**Table 1.** Spectral fit results

	BAT	XRT
$N_h$ (cm $^{-2}$ )	–	$(7.5^{+4.3}_{-3.2}) \times 10^{20}$
$\Gamma$	$1.1 \pm 0.3$	$1.54 \pm 0.16$
$\chi^2_{red}$ (d.o.f.)	1.0 (57)	0.78 (25)

conversion factor derived from the spectral analysis. The X-ray afterglow is detected only in the first 1000 s after the onset. The XRT light curve can be modelled with a single power law with decay index  $2.58 \pm 0.11$ . The flare in the early afterglow is well described by a Gaussian centered at  $134 \pm 2$  sec with  $\sigma = 10 \pm 2$  s. The inclusion of this component in the fit improves the  $\chi^2_{red}$  (d.o.f.) from 2.17(23) to 1.14(20), with F-test chance probability of  $1 \times 10^{-3}$ . A second Gaussian centered at  $216 \pm 44$  sec yields a further marginal improvement to the fit, with F-test chance probability of  $4 \times 10^{-2}$ .

In order to compare the decay before and after the flares, we made an estimate of the decay slope before the flares by comparing the photon arrival times in the first 26 seconds of the *wt* mode observation with power laws with different slopes through a Kolmogorov-Smirnov test. We get  $\alpha_{wt} = 2.35^{+0.20}_{-0.30}$ , where the best value is the one that maximizes the probability that the photon arrival times follow a power law distribution, and the quoted errors define the interval of the slope values for which the test provides an “acceptance” probability higher than 90%. This slope is consistent both with the average decay and with the late time light curve.

The XRT spectrum (Fig 3, Table 3) is relatively hard and can be well described with an absorbed power law ( $\Gamma = 1.54 \pm 0.16$ ) with absorption slightly in excess with respect to the Galactic line of sight value ( $2.2 \times 10^{20}$  cm $^{-2}$ , Dickey & Lockman, 1990). All quoted errors are at 90% confidence level.



**Fig. 3.** XRT 0.2-10 keV and BAT 15-150 keV energy spectra of GRB 051210, with the best-fit absorbed power law model and residuals. The BAT and XRT data are not simultaneous.

#### 4. Discussion

GRB051210 is one of the few short GRBs for which we have an X-ray detection and an accurate location. Its X-ray light curve

decays rapidly and the X-ray counterpart is not detectable any more after  $\sim 1$  ks. The X-ray light curve decays as a power law with slope  $\alpha = 2.57 \pm 0.11$ . Superimposed on it we detect a flare peaking at T+134 s, and a less significant bump at T+216 s. The BAT and XRT spectra can be described with a power law, with photon indexes  $1.0 \pm 0.3$  and  $1.54 \pm 0.16$  respectively. The shape of the light curve is very similar to that of GRB050421 (Godet et al., 2006). The rapid fading of the source and the lack of any flattening in the light curve after the first steep decay may indicate that the GRB occurred in an extremely low density medium (naked GRB, Kumar & Panaitescu, 2000; Page et al., 2005) where the radiation emitted by the forward shock, generated by the impact of the initial shock front with the surrounding interstellar medium, is expected to be undetectable. The steep decay of the X-ray emission is fully consistent with the hypothesis that we are observing a low energy tail of the prompt emission from an internal shock through the so-called curvature effect (Kumar & Panaitescu, 2000; Dermer, 2004; Zhang et al., 2006): the radiation observed as the tail of a peak is expected to be the off-axis emission of the shocked surface arriving at the observer at later times, and would decay as  $t^{-\alpha} = t^{-(\Gamma+1)}$ , where  $\Gamma$  is the photon index of the GRB emission. In the case of GRB051210 we get  $\alpha = \Gamma + 1 = 2.54$ , in very good agreement with the observed slope ( $2.57 \pm 0.11$ ). However, the extrapolation of the XRT light curve back to the burst onset does not match the BAT points by a few decades. This could well be due to the fact that the XRT light curve is in fact the tail of a flare peaked at the time before the XRT observation and too weak to be detected by the BAT. Within such an interpretation, the zero time point of the rapid decay component should be shifted to the beginning of the rising segment of the relevant flare (Zhang et al., 2006; Liang et al., 2006), which marks the reactivation of the central engine. Visual inspection of the lightcurve suggests that this time is about 10 s. We then re-fit for the decay index after such a shift. The temporal decaying slope is changed  $2.59 \pm 0.08$ , which is still consistent with the theoretical predicted value  $\alpha = \Gamma + 1 = 2.54$ .

If we are seeing only the tail of the prompt emission, and the afterglow is not detectable, we can derive an estimation for the density of the interstellar medium  $n$  in the vicinity of the burst. Assuming  $F_{LIM} = 1 \times 10^{-14}$  erg cm $^{-2}$  s $^{-1}$  to be the limiting flux in our observation, and considering that we have no detectable emission at  $T_0 + 10^4$ , we can infer  $n$  from the expression of the expected afterglow flux according to the standard afterglow models (Sari & Esin, 2001; Sari, Piran & Narayan, 1998). We assume as  $z$  the average redshift measured for short GRBs up to now (0.35), and estimate the energy of the afterglow ( $E_a$ ) from the 1-1000 keV fluence of the prompt emission, as indicated by (Frail et al., 2001). We account for the decay of the afterglow at a time  $T_0 + 10^4$ , assuming an electron index  $p=2.2$  and we assume to be at a frequency between the peak frequency  $\nu_m$  and the cooling frequency  $\nu_c$ . With these assumptions, we get  $n < 4 \times 10^{-3}$ , that confirms the trend put in evidence by Soderberg et al. (2006), that short GRBs tend to be in low-density environments. We note that the estimate of  $n$  is subject to uncertainties of  $z$ ,  $E_a$  and  $p$  (e.g. it increases with  $z$  and  $p$  but decreases with  $E_a$ ). In any case, the inferred den-

sity is lower than the typical values inferred from long GRBs (Panaiteescu & Kumar, 2002).

Flaring activity has been previously observed in other short GRBs: GRB050709 (Fox et al., 2006), that shows a flare between 25 and 130 s and a late flare at about 16 d, and GRB050724 (Barthelmy et al., 2005b; Campana et al., 2005), that shows at least four flares. Interestingly, the epoch of the first flare is  $\sim 100$  s for both of those two events and for GRB051210. Moreover, evidence for X-ray emission at this timescale has been reported in the stacked light curves of several BATSE short GRBs (Lazzati et al., 2001). Delayed activity from the inner engine has been generally invoked to interpret flares (Burrows et al., 2005; Zhang et al., 2006; Romano et al., 2006; Falcone et al., 2006). This is less problematic for long duration GRBs since in the collapsar scenario, there is a large reservoir of the fuel and the fragmentation or gravity instability in the collapsing star may form clumps that are accreted at different times, leading to delayed X-ray flares (King et al., 2005). However, this cannot be applied to short GRBs, if we accept the hypothesis that they originate in the merger of two compact objects in a binary system (NS-NS or NS-BH), a scenario supported by the recent observations. Hydrodynamical simulations suggest that the central engine activity of merger events cannot last more than a few seconds (Davies et al., 2005). Perna et al. (2006) suggest a common origin for flares in long and short GRBs: some kind of instability (likely gravitational instability) can lead to the fragmentation of the rapidly accreting accretion disk that forms after the GRB (both in the collapsar and in the merger model), creating blobs of material whose infall into the central object produces the observed flares. Proga & Zhang (2006) suggest that magnetic fields may build up near the black hole and form a magnetic barrier that temporarily block the accretion flow. The interplay between the magnetic barrier and the accretion flow can turn on and off the accretion episodes, leading to erratic X-ray flares at late epochs. This mechanism also applies to both long and short GRBs. Dai et al. (2006) propose that the postmerger product for the NS-NS system may well be a massive neutron star if the neutron star equation of state is stiff enough. The differential rotation of the neutron star would lead to windup of magnetic fields, leading to magnetic reconnection events that power X-ray flares. These scenarios are all consistent with a magnetic origin of the flares based on energetics arguments (Fan et al., 2005). Finally, an alternative hypothesis has been formulated by MacFadyen et al. (2005): the interaction of the GRB outflow with a noncompact stellar object is suggested as a natural explanation for a flare after the burst. This model is restricted to interpret only one flare (and therefore cannot be applied to GRB 050724 but may be relevant for GRB 051210) and the outflow is required to be not collimated. In any case, the presence of a flare at a similar epoch (around 100 s) in three out of five short bursts observed by now, if also confirmed by future short GRBs, is a point that is worth investigating and calls for better understanding.

This work is supported at INAF by funding from ASI, at Penn State by NASA and at the University of Leicester by the Particle Physics and Astronomy Research Council. We gratefully acknowledge the contribution of dozens of members of

the XRT team at OAB, PSU, UL, GSFC, ASDC and our sub-contractors, who helped make this instrument possible.

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